

# The ZEUS Micro Vertex Detector

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## Abstract

During the HERA luminosity shutdown period 2000/01 the tracking system of the ZEUS experiment has been upgraded with a silicon Micro Vertex Detector (MVD). The barrel part of the detector consists of three layers of single sided silicon strip detectors, while the forward section is composed of four wheels. In this report we shortly present the assembly procedure and in more details the test beam results on the spatial resolution of half modules. The first results of a cosmic ray test are presented and the radiation monitor system is described.

*Key words:* Vertex; Silicon; ZEUS

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## 1 Introduction

ZEUS is a multi purpose detector operating at the Hadron Electron Ring Accelerator (HERA) located at the DESY laboratory in Hamburg, Germany. At HERA 27.5 GeV electrons collide with 920 GeV protons, corresponding to a center of mass energy of 318 GeV. The integrated luminosity recorded by the ZEUS detector during the first period of data taking (from 1993 to 2000) is about  $130 \text{ pb}^{-1}$ . A shutdown period has then followed to allow the luminosity upgrade of HERA [1] and the installation of new components in ZEUS, including a silicon Micro Vertex Detector which, besides a general improvement and extension of the track reconstruction, will allow the identification of final states containing long-lived particles.

Fig. 1 shows the layout of the Micro Vertex Detector (MVD) parallel to the beam axis. We distinguish a forward (FMVD, proton direction) and a central (BMVD, barrel) section. The barrel section is about 65 cm long and consists of three layers of silicon strip sensors arranged in cylindrical planes surrounding the interaction point. Each layer is composed by two planes of single-sided

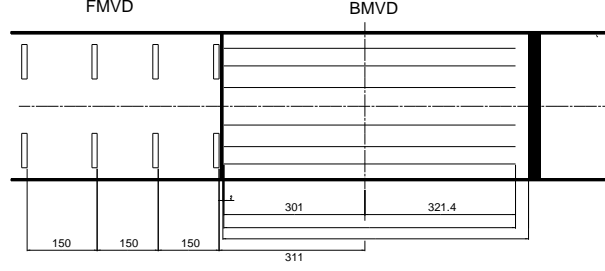


Figure 1. *Layout of the MVD along the beam line.*

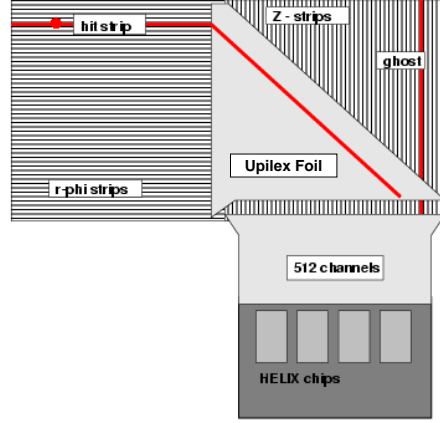


Figure 2. *Schematic view of a half module.*

silicon strip detectors<sup>1</sup> (320  $\mu\text{m}$  thick) with  $p^+$  strips implanted into a  $n$ -type bulk. The strip pitch is 20  $\mu\text{m}$  but only every 6th strip is AC coupled to an aluminium readout line. In the barrel section two sensors are glued together and one sensor is electrically connected to the other via a copper trace etched on 50  $\mu\text{m}$  thick Upilex<sup>2</sup> foil (see Fig. 2). The connection of the sensor assembly with the front end readout is also made via a Upilex foil, glued at one side on the sensor and at the other side on the hybrid. The resulting surface of 123.68 x 64.24 mm<sup>2</sup> forms one readout cell of 512 channels and is called a *half module* [2].

The forward section consists of four wheels, each of them made of two layers of 14 silicon sensors of the same type of the barrel section but with a trapezoidal shape. In each wheel the two layers are parallel but strips are tilted by  $180^\circ/14$  in opposite directions.

A more detailed description of the MVD layout and of the silicon sensors can be found in Refs. [3–6].

<sup>1</sup> produced by Hamamatsu Photonics.

<sup>2</sup> Polyimide film produced by UBE Technologies Ltd, Japan

## 2 Assembly and survey

The assembly of the barrel section proceeds as follows:

- Using precision rotational and translation tools the sensors are glued together to form the half module with a precision of  $10\ \mu\text{m}$ . This precision is defined as the maximum uncertainty on the distance of one reference mark to the one of another sensor. Two half modules (the one in Fig. 2 and its mirrored image) are mounted on top of each other forming a *full module*.
- Five full modules are fixed side by side, with 1 mm gap in between, on a support frame and form a *ladder*. After assembly the position of the half modules are measured. Within one ladder a precision of  $5\ \mu\text{m}$  is achieved.
- In order to assemble the MVD and the beam pipe together before installation in ZEUS, the detector has been arranged in two separate half cylinders. The ladders are mounted in a half cylinder supported on ceramic spheres on the front side and by two screws on the rear. After assembly the ladder position is measured with a 3D survey machine to a precision of  $10\ \mu\text{m}$ . A total of 30 ladders has been installed in the BMVD.

## 3 Program of test and measurements before installation

### 3.1 Test beam measurements

A test beam program has been set up to understand the performance of our silicon detectors and front end electronics. Results on single sensors have been presented in Ref. [7–9]. Half modules of the final production chain have been exposed to an electron beam of 2–6 GeV at the DESY II accelerator. The charged tracks are measured by three pairs of silicon strip detectors with  $50\ \mu\text{m}$  readout pitch and one intermediate strip, providing a position accuracy of  $5.4\ \mu\text{m}$  for a 6 GeV beam.

The charge created by a traversing particle is collected by several consecutive strips, which form a *cluster*. In order to find the cluster we first look for the strip whose charge is higher than a given threshold. The threshold was defined as  $5\sigma$ , where  $\sigma$  is the r.m.s. noise of each strip. The reconstruction of the impact position has been performed with three different algorithms, i.e. (1) the Eta algorithm [10–12], (2) the Double Centroid algorithm, (3) the Head–Tail algorithm.

- (1) *Eta algorithm*: is based on the assumption that most of the charge is collected by the two readout strips closest to the impact position. If  $Q_{\text{left}}(Q_{\text{right}})$  is the charge collected on the left(right) side of the impact

point,  $P$  the readout pitch and  $x_{left}$  the position of the left strip, the hit position  $x_{Eta}$  can be reconstructed by

$$x_{Eta} = P \cdot f(\eta) + x_{left} \quad (1)$$

with:

$$\eta = \frac{Q_{right}}{Q_{right} + Q_{left}}, \quad f(\eta) = \frac{1}{N} \int_0^\eta \frac{dN}{d\eta'} d\eta'. \quad (2)$$

In Eq. 2  $\eta$  is calculated for each hit, while the probability function  $f(\eta)$  is evaluated using all hits of each data sample.

- (2) *Double Centroid algorithm (DC)*: reconstructs the impact position using the strip with the highest collected charge and its two neighbouring strips. Having computed the center of gravity  $C_{left}(C_{right})$  between the central strip and the left(right) neighbouring strip, the hit position is given by

$$x_{DC} = \frac{C_{left}/dr + C_{right}/dl}{dr + dl}, \quad dl = \frac{Q_{left}}{Q_{right}} = 1/dr. \quad (3)$$

- (3) *Head-Tail algorithm (HT)*: for large incident angles, the charge generated by a particle spreads among many strips. In this case, the charges collected by central strips in the cluster do not contain position information. The Head-Tail algorithm uses the information from strips on both edges to solve this problem. We define the head(tail) strip as a strip which has the smallest(largest) strip number and collected charge higher than three times the noise level. The hit position  $x_{HT}$  is then given by

$$x_{HT} = \frac{x_h + x_t}{2} + \frac{Q_t + Q_h}{2Q_{AV}} \cdot P \quad (4)$$

where  $x_h(x_t)$  is the position of the head(tail) strip and  $Q_h(Q_t)$  its charge. The average pulse height per strip within the cluster is  $Q_{AV}$ .

Fig. 3 shows the intrinsic resolution measured on a half module as a function of the incident angle (with respect to the normal direction) with different hit reconstruction algorithms and a 6 GeV beam. The best achieved intrinsic resolution for perpendicular tracks is 13  $\mu\text{m}$  with the Eta algorithm as compared with 9  $\mu\text{m}$  obtained with the single sensor [7]. The DC algorithm has a slightly worse resolution (17  $\mu\text{m}$ ) but does not need the evaluation of the probability function Eq. 2, as in the case of the Eta algorithm. For incident angles greater than 40 degrees the HT algorithm gives the best performance.

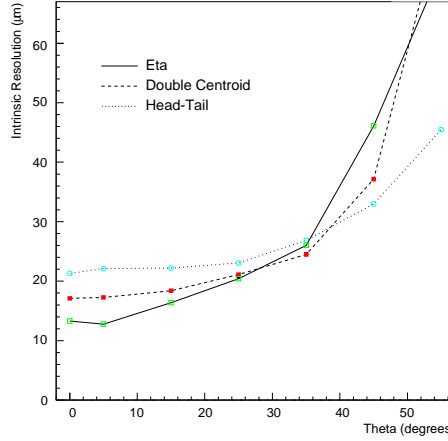


Figure 3. *Intrinsic resolutions as a function of the incident angle, measured with different hit reconstruction algorithms.*

### 3.2 Test of half module electrical properties

A full module and two half modules (an inner and an outer one) were selected for a series of I/V measurements (i.e. dark current vs bias voltage) and endurance test as a function of temperature and humidity. A full module was assembled in the same way as the ones used on the ladders in the MVD. The module was placed in a box and the temperature was monitored with a NTC resistor. Fig. 4 shows the I/V curves measured on the inner half module at different temperatures (14, 20, 23 and 30° C). We observe an increase of the breakdown voltage with the increase of temperature as well as the expected overall increase of dark current. During these measurements humidity was not controlled neither recorded.

Further measurements were performed on half modules. The temperature in the box was regulated with a Peltier element and humidity was monitored by a sensor Humicor S6000 (of the type used in the ZEUS MVD). The humidity level inside the box was controlled by nitrogen flow. The results of these measurement are shown in Fig. 5. The clear dependence of the breakdown voltage on the humidity level leads us to the conclusion that careful checking and control of the humidity is required for the MVD.

### 3.3 System test with cosmic rays

After the assembly of the detector half cylinders together with the beampipe the MVD has been connected to the final readout electronics, including the final set of power and signal cables. We summarise the tests performed in the

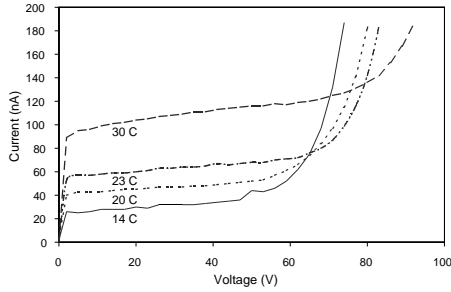


Figure 4. *I/V curves measured on an inner half module for five different temperatures, see text.*

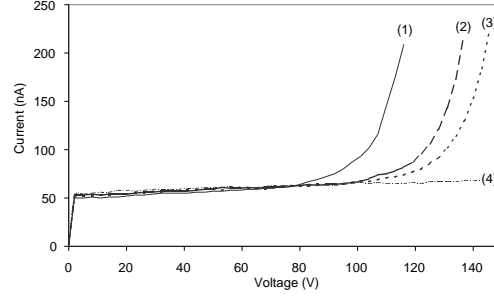


Figure 5. *I/V curves measured on an inner half module at 22 °C and different relative humidity: 62.2% (1), 60% (2), 55% (3) and 31% (4).*

following points:

- A fast scope test consisting in programming and checking the response of all front end chips;
- Test of data acquisition system with a random trigger;
- Data acquisition with cosmic ray trigger;
- Test of slow control system.

Already from the scope test two full modules (over a total of 206) and a single front end hybrid have been found to be faulty; no further degradation has been observed. The system has been running continuously for four weeks in cosmic trigger mode, recording a total of about 2.5 million events. A first analysis of cosmic events has been performed requiring at least two good hits in both projections in the modules of the outer layer. The hit position has been calculated using a center of gravity algorithm, while the track trajectory has been extrapolated with a Kalman fit. Input for these calculations is the geometrical position of the detectors resulting from the design. The distribution of residuals without any alignment correction shows a resolution of  $70 \mu\text{m}$  in  $r\text{--}\phi$  coordinate and of  $80 \mu\text{m}$  in  $r\text{--}z$  coordinate.

## 4 Radiation monitoring

The radiation monitor system (RadMon) for the MVD has the following main tasks:

- Provide continuous monitoring data and generate warning signals to the ZEUS shift crew in case of a moderately high radiation;
- Provide a fast dump signal to the electron kicker of HERA in case the radiation is too high;
- Calculate the total integrated dose.

The maximum tolerable dose in our electronics is 3 kGy, with already degradations in the S/N ratio after 1 kGy which can be partly recovered by tuning of the front end parameters. The design lifetime is 5 years of operation in the HERA environment, which sets the acceptable dose to 250 Gy/yr. The detectors chosen for the RadMon are 8 pairs of oxygen enriched silicon PIN diodes (1 cm<sup>2</sup> active surface, 300  $\mu$ m thickness), placed near the beampipe in the forward and rear part of the MVD. The two diodes forming a pair are mounted back to back with 1 mm of lead in between to discriminate background of charged particles from synchrotron radiation.

In addition, in the rear region six plastic tubes have been glued on the beam pipe shield and are used to insert TLD dosimeters, providing a monthly dose measurement.

## 5 Conclusions

The micro vertex detector has been successfully assembled and installed in the ZEUS experiment. A set of test beam measurements on half modules shows that we have achieved an intrinsic spatial resolution of 13  $\mu$ m for perpendicular tracks. The detector has been equipped with a radiation monitoring system and is currently participating to the commissioning of the HERA beams. The luminosity run will start in 2002.

## 6 Acknowledgements

I would like to thank all my colleagues of the ZEUS MVD group, in particular R. Carlin, U. Koetz, E. Koffeman and H. Tiecke for the useful discussions.

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